The Carbon TrapRock Project

The Carbon TrapRock Project, led by the Yale Carbon Containment Lab in collaboration with the Pacific Northwest National Lab (PNNL), federal and state officials, and industrial partners, **aims to store billions of tons of carbon dioxide permanently and safely, provide jobs restoring forest health, and reduce catastrophic wildfire risk in the Pacific Northwest.**

Increased stress from drought, pests, and disease, combined with suppression of low-intensity fires and the collapse of markets for small-diameter trees, has resulted in catastrophic fires in the Pacific Northwest. These fires, linked to overstocked dead and low-value wood fuel, have increased in frequency and intensity over the last 10 years. Although most forests are excellent stores of carbon, approximately 30% of the federal forests in eastern Washington and Oregon are severely stressed and experience more tree mortality than growth. Over 90% of severe forest fires in the Pacific Northwest originate from federal forests, but federal forest restoration programs that promote resiliency have been chronically underfunded, and are not being implemented at the scale required to mitigate fire risks.

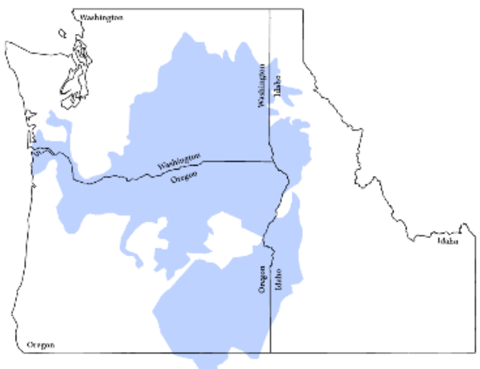
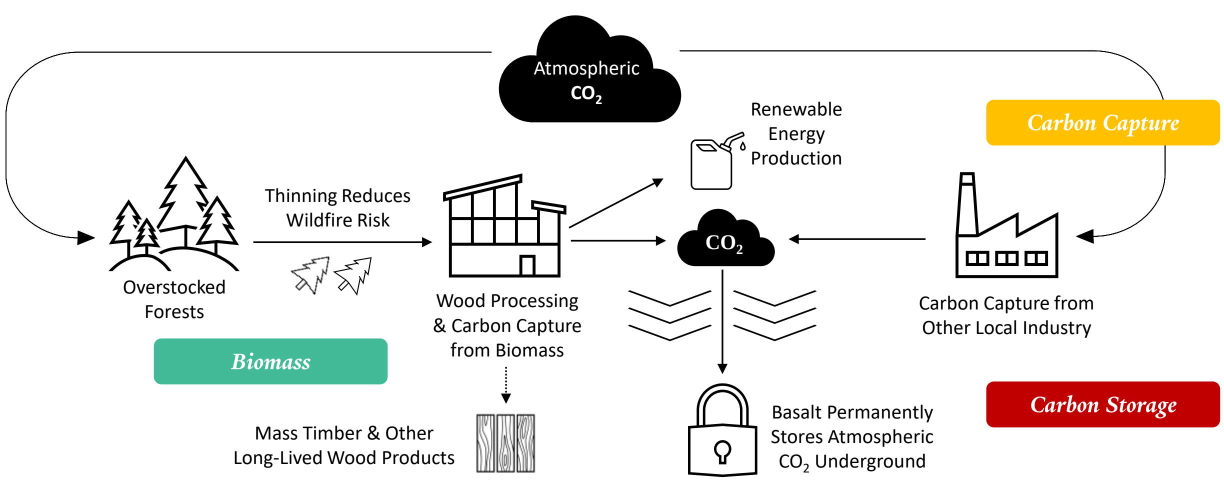


Exhibit 1: Extent of the Columbia River Basalt Group. Source: USGS/DOE.

The Pacific Northwest is also home to one of the world's biggest natural resources for permanently and safely storing CO_2, in the lava formation known as the Columbia River Basalt Group (CRBG). The region also contains significant quantities of CO_2 in the form of overstocked forests that are at high risk for severe wildfire. The CRBG spans 210,000 km^2 across Oregon and Washington, also dipping into Idaho, and California. CO_2 injected deep into these basalts mineralizes and forms carbonate rock. From 2009-2015, PNNL drilled and injected CO_2 into a pilot well in Wallula, Washington, where they demonstrated rapid carbon sequestration via in-situ mineralization. Further pilot testing is needed to characterize the best CRBG locations for sequestration, and to better understand mineralization rates and total capacity. Researchers at PNNL estimated the storage capacity of the CRBG to be as much as 100 billion metric tons of CO_2, though storage of even 1 billion metric tons would be a significant portion of total U.S. annual emissions.

The Carbon TrapRock project envisions an end-to-end solution that converts biomass and other sources of CO_2 into carbonate minerals alongside useful by-products, as shown below. One of the pathways of interest is to convert into CO_2 the large amounts of dead and low-value wood that must be removed to



mitigate future wildfire risk and restore forest health. Currently, most of this waste wood is left in the forest to decompose or burn. Innovative gasification plants break down the woody biomass to create low carbon fuels and concentrated CO_2 as a byproduct, as shown in Exhibit 2.

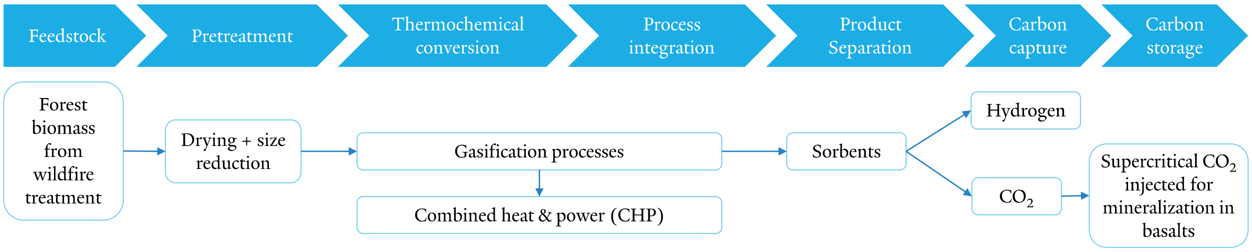


Exhibit 2: Potential pathway for gasification, carbon capture, and carbon storage for PNW low-value biomass. Source: Yale CC Lab 2021.

Carbon TrapRock would pressurize the CO_2 and inject it over 2,500 feet below the surface into the basalt, where it mineralizes and remains permanently and safely stored. Termed *in situ mineralization*, this process involves the formation of solid carbonate minerals (calcite, magnesite, ankerite, dolomite, and a variety of hydrated magnesium-carbonate minerals) through the reaction of CO_2 (gas, liquid, dissolved in water, or supercritical) with calcium-, iron- and magnesium-rich rocks.

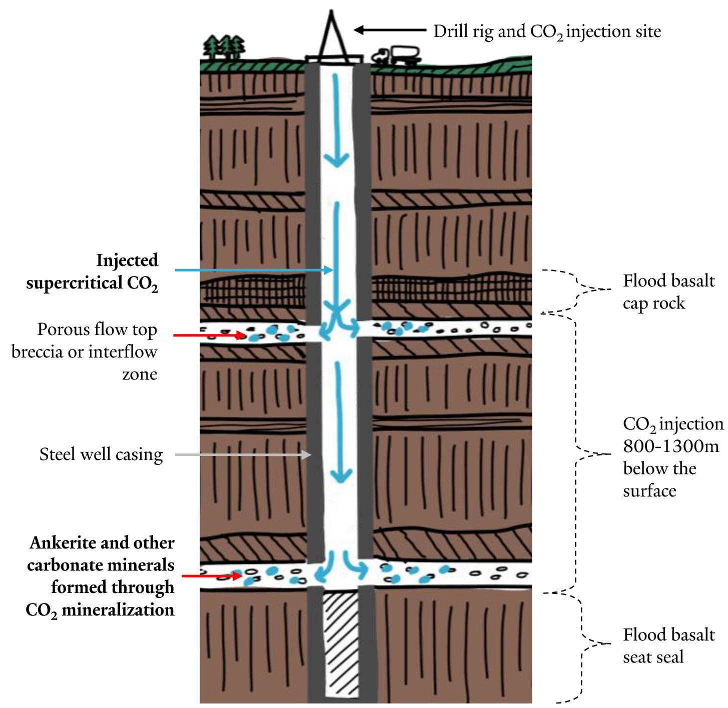


Exhibit 3: Diagram of basalt CO2 injection well method, where the CO_2 is injected into the basalt at high pressures before mineralization. Source: Yale CC Lab 2021.

Preliminary cost estimates indicate that this process could be financially sustainable with funding from 45Q tax credits, carbon offsets, and forest restoration funding. Additional revenues may come from low carbon fuel premiums.

Studies and a Pilot

The CC Lab is currently conducting several studies to validate the feasibility of this concept, including techno-economic and lifecycle assessments, a study of logs from over 40 existing wells in the CRBG, a source-to-sink analysis of the sequestration potential, and investment analysis. In addition, we are engaging permitting authorities, federal and state agencies, regional geology and legal specialists, and other stakeholders, including Tribal Nations, who hold rights to land in the region of interest as well as forestry assets.

To expand this project, a larger pilot is being prepared for a funding request to the Department of Energy and private funders. The pilot will determine the regional potential for basalt sequestration by better understanding the region's basalt mineralization rates, capacity in multiple horizons and locations, and the infrastructure necessary to collect, capture, and transport supercritical CO_2 to optimal injection locations.

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